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SEISMIC RESPONSE OF GEOSYNTHETIC/SOIL SYSTEMS

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Abstract

An experimental investigation of the dynamic interface shear strength properties of a geomembrane/soil (Ottawa sand) system is conducted using shaking-table tests. Results show the shear stress and therefore acceleration that can be transferred through the interface is limited. Beyond this acceleration, relative displacement (slip deformation) occurs along the interface. The force-displacement relationship for a geomembrane/geotextile interface is also investigated. This relationship indicates a rigid and then plastic deformation where the maximum shear force transmitted increases with increasing slip deformation. A stick-slip behavior along the geosynthetics interface is also observed, which momentarily increases the shear force transferred through the interface. The dynamic shear behavior of the geomembrane (HDPE)/Ottawa sand interface is also tested under earthquake-type excitation. The yield acceleration for the HDPE/Sand interface varies from one pulse to another. The response spectrum of the motion transmitted through the HDPE/Sand interface and the spectrum of the shaking table motion are compared to understand the dynamic interface shear behavior under earthquake-type excitation.

Introduction

Seismic design considerations for landfills continue to receive increased attention in practice. The US Code of Federal Regulation, Protection of Environment, (1992) (Title 40), requires that all landfills within a "seismic impact zone" be designed for a level of acceleration of not exceeding 90% or greater probability in 250 years. A "seismic impact zone" is defined as a region within which the maximum horizontal acceleration for the stated probability level is

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greater than 0.1g. A seismic hazard map prepared by U.S.G.S. (1991) shows the levels of acceleration to be considered for landfills across the United States. From this map it can be observed that landfills located in most parts of the country will have to be designed for earthquakes according to the level of acceleration indicated on the map.

Although there is urgency in engineering practice to address design issues related to landfills, to date, there has been little research done to evaluate the dynamic properties of landfill materials, and to understand their seismic response. For this reason, in August 1993, supported by the National Science Foundation, the GeoSyntec Consultants (Dr. Edward Kavazanjian) and the University of Southern California (Dr. Geoffrey Martin) organized a workshop to define the critical research needs related to seismic design of municipal solid-waste landfills. The workshop identified the following key research areas:

1- Dynamic properties of landfill materials and geosynthetic interface properties,
2- Dynamic response analysis of landfills, and
3- Design and performance criteria including limits and types of deformation that a landfill can tolerate during an earthquake.

During the past few years, the authors have been conducting research on the first and second topics. Their initial research results on dynamic interface properties between geomebrane and geotextile, using a small shaking table, were published by Yegian and Lahlaf (1992). Subsequent to that work, the researchers built a larger shaking table and developed a new experimental set-up to conduct investigations on the dynamic response of geosynthetic/soil interfaces. This paper presents a description of the shaking table facility developed, as well as results obtained from dynamic tests on a geomembrane/geotextile and a geomembrane/soil interfaces under harmonic and earthquake type excitations.

Shaking Table Facility

A shaking table facility was designed and manufactured at Northeastern University to investigate interface shear properties of geosynthetics under harmonic, as well as real earthquake-type excitations. Figure 1 shows a schematic diagram of the test setup for investigating the dynamic interface shear properties between two geosynthetics. Essentially, a rigid heavy block of lead is placed on one geosynthetic -in our tests a piece of polyfelt TS 700: Nonwoven, continuous filament, needlepunched geotextile-, which in turn is placed on a geomembrane - smooth 60MIL HDPE- fastened to the shaking table. During a test, the accelerations of the block and the table together with the relative displacement between the block and the table are recorded. Yegian and Lahlaf (1992) have related the peak acceleration of the block a_b to the dynamic interface friction angle $Ø_d$ by Equation 1.

$$a_b = g \tan Ø_d \qquad (1)$$

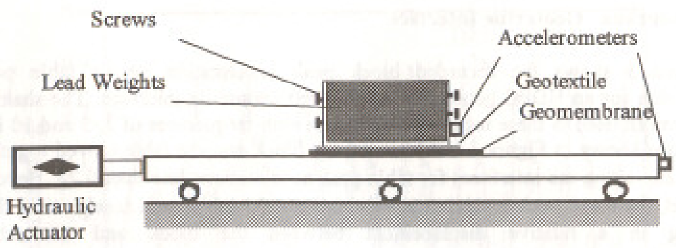

Figure 1. Schematic Diagram of the Test Setup for Investigating the Dynamic Shear Properties of Geomembrane/Geotextile Interface.

A schematic diagram of the shaking table facility used to test dynamic interface properties of geosynthetic/soil is shown in Figure 2. In preparing a geosynthetic/soil interface for testing, first a geomembrane is fixed to the surface of the shaking table. Then an 8 in x 10 in plexiglass box with no top or bottom plates is placed on the geomembrane. Geotextile strips are glued along the bottom edge of the plexiglass walls to avoid direct contact of the uneven edge of the plexiglass box on the geomembrane. This geotextile strip also prevents soil from escaping from inside the box during shaking. In tests reported in this paper, Ottawa sand was placed inside the box to a depth of 1 inch. The sand was vibrated to achieve its maximum density, thus avoiding possible change in density during the shaking. Over the sand layer and inside the plexiglass box, a roughened plexiglass plate was placed. Blocks of lead weights rested over the sand and the plexiglass plate to increase the normal stress to 12.4 kpa (1.8 psi) at the interface. Complete horizontal contact was achieved between the lead weights and the plexiglass box by tightening small screws from the outside of the plexiglass walls. The points of contact of the screws and the lead weights were smoothened to ensure that no vertical shear was transferred from the weights to the box. In all tests, the accelerations of the box and the table were recorded together with the relative displacements (slip) along the interface.

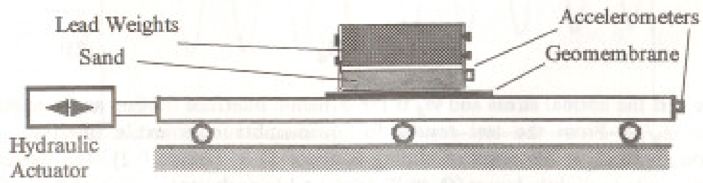

Figure 2. Schematic Diagram of the Test Setup for Investigating the Dynamic Shear Properties of Geomembrane/Soil Interface.

Geomembrane / Geotextile Interface

Figure 3 shows the recorded block peak acceleration versus table peak acceleration for an HDPE geomembrane/Polyfelt geotextile interface. The shaking table motions used in these tests were harmonic with frequencies of 2, 5 and 10 Hz. The results shown in Figure 3 indicate that the block and the table moved together (i.e. no slip along the interface) for table peak accelerations less than 0.2g. Beyond this level, the block peak acceleration was less than the table peak acceleration, thus resulting in a relative displacement between the block and the table.

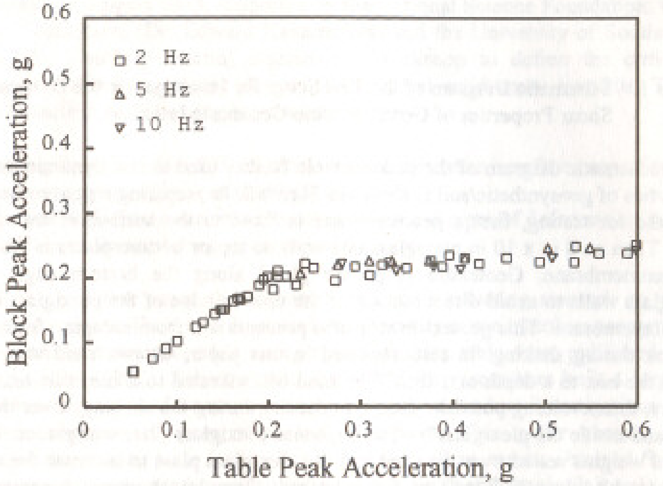

Figure 3. Recorded Block Peak Acceleration Versus Table Peak Acceleration for HDPE Geomembrane/Geotextile Interface.

These tests indicate that there is a limiting shear stress that can be transmitted from a geomembrane to a geotextile. This maximum shear resistance can be expressed as:

$$\tau = \sigma \tan \varnothing_d \qquad (2)$$

where σ is the normal stress and $\varnothing_d$ is the dynamic interface friction angle equal to arctan (a_b/g). From the test results for geomembrane/geotextile interface, the friction angle $\varnothing_d$ at the onset of sliding is about 11.3° (arctan 0.2). The dynamic friction angle is slightly larger ($\varnothing_d$ = 13.5°) for table peak acceleration of 0.6g. This increase is further discussed in the following section. The normal stress, increased to 51.8 kpa (7.5 psi), has no influence on the results.

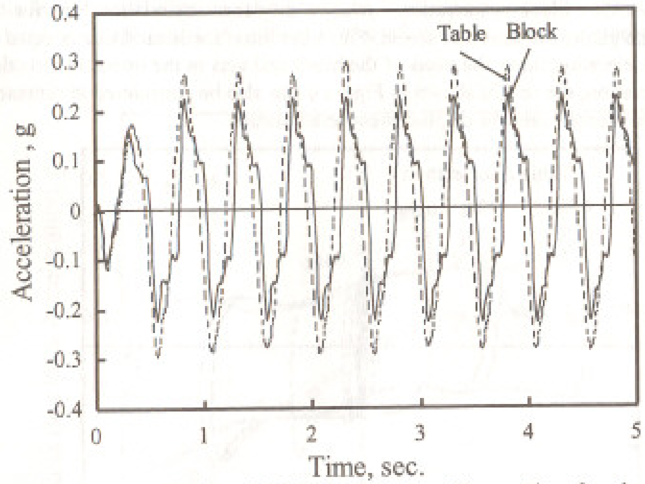

Figure 4. Recorded Block and Table Accelerations Versus Time for the Geomembrane/Geotextile Interface.

Figure 4 shows a typical block and table accelerations for table motion frequency of 2Hz. When the table peak acceleration was 0.3g, the block could only accelerate with a peak of about 0.21g. Thus relative displacements (slip) occurred along the geosynthetic interface tested. Figure 5 shows the recorded slip which has a peak to peak amplitude of about 0.75 in.

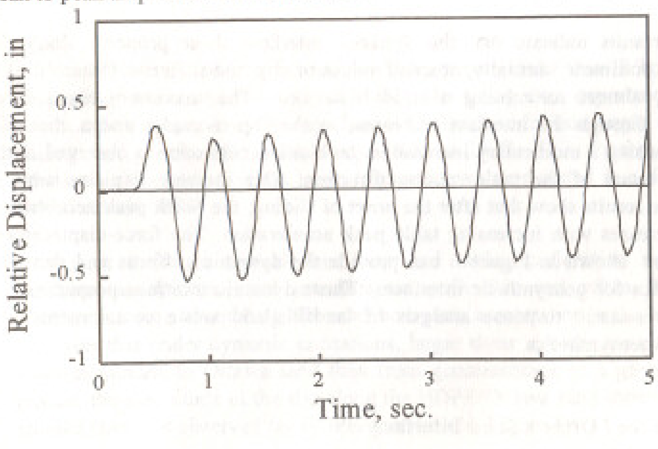

Figure 5. Recorded Relative Displacement (slip) Versus Time along the Geomembrane/Geotextile Interface.

Figure 6 shows block acceleration - relative displacement relationships for the geomembrane/geotextile interface tested. Since the interface shear force is equal to the block acceleration times the mass of the block and acts in the opposite direction as the acceleration, the results shown in Figure 6 can also be considered to represent interface shear force - relative displacement relationships.

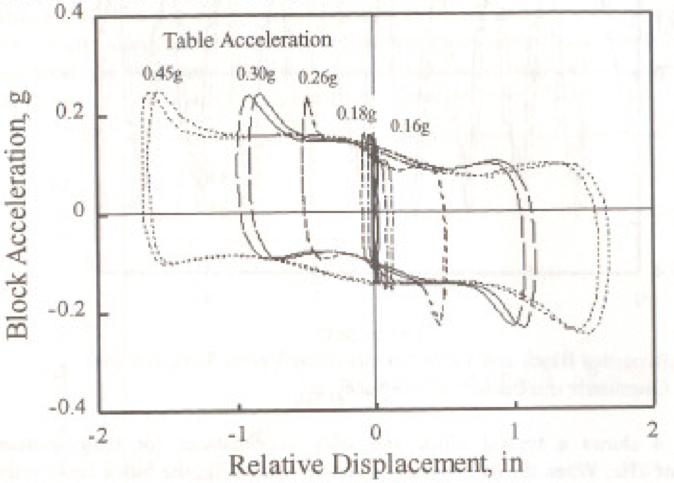

Figure 6. Block Acceleration (Interface Shear Force) - Relative Displacement Relationships for Geomembrane/Geotextile Interface at Various Table Accelerations.

These results indicate that the dynamic interface shear property along the interface is nonlinear. Initially, at small values of slip, the stiffness (force /slip) is very large, almost resembling a rigid behavior. The maximum shear force transmitted through the interface increases, as the slip increases and a stick-slip behavior causing a momentary increase in the block acceleration is observed at the time of reversal of the table motion direction. This increase explains why in Figure 3 the results show that after the onset of sliding, the block peak acceleration slightly increases with increasing table peak acceleration. The force-displacement relationships shown in Figure 6 can provide the dynamic stiffness and damping characteristics for geosynthetic interfaces. These dynamic interface properties can be used in seismic response analysis of landfills and waste containments that incorporate geosynthetics.

Geomembrane / Ottawa Sand Interface

The shaking table tests described in the previous section were repeated using a smooth geomembrane fixed to the table and the soil box described earlier. The soil

in the box was Ottawa sand placed as described previously. Figure 7 shows the sand box peak acceleration as a function of the table peak acceleration.

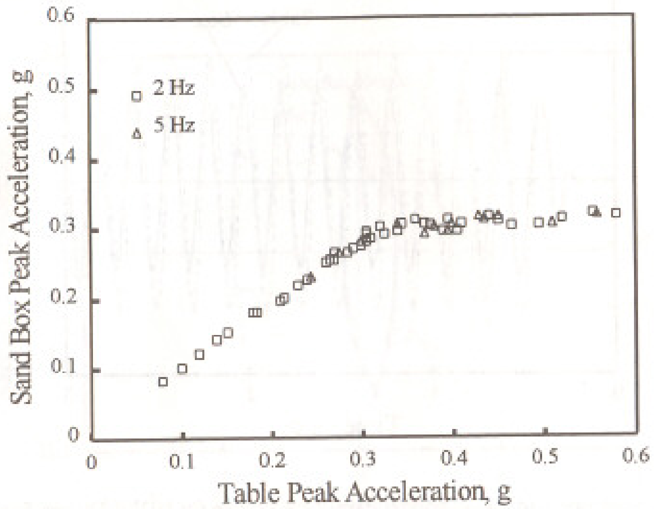

Figure 7. Sand Box Peak Acceleration Versus Table Peak Acceleration for Table Motion Frequencies f = 2 Hz and 5 Hz.

Again, it is noted that for table accelerations greater than 0.3g the sand box accelerates at a smaller acceleration than the table, thus experiencing a relative displacement (slip) along the interface. The dynamic friction angle at the onset of sliding can be obtained from arctan (0.3) = 16.7°. This friction angle is also identical to the static friction angle of the Ottawa sand tested in a direct shear test (Martin et al., 1984).

Figure 8 shows typical sand box and table acceleration records for the geomembrane/Ottawa sand interface tests. In this test when the table peak acceleration was about 0.4g the sand box peak acceleration was about 0.3g. This indicates that under dynamic excitations, larger shear stresses are transmitted from a geomembrane to Ottawa sand than from geomembrane to a geotextile. For this reason, the magnitude of the slip along the HDPE/Ottawa sand shown in Figure 9 is smaller than that observed for HDPE/geotextile in Figure 5.

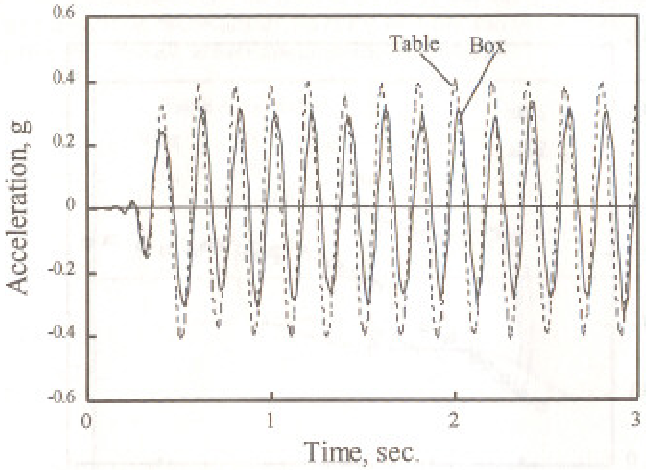

Figure 8. Sand Box and Table Acceleration Versus Time for HDPE/Ottawa Sand Interface.

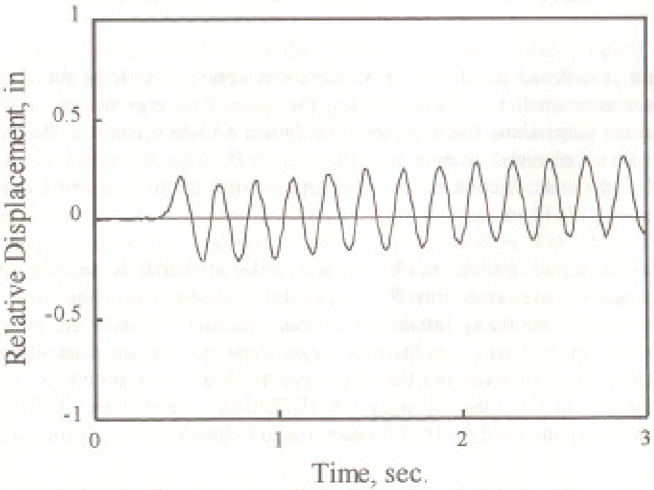

Figure 9. Relative Displacement (Slip) Versus Time for HDPE/Ottawa Sand Interface.

Figure 10 shows the sand box acceleration (interface shear force) - displacement relationships for the HDPE/Ottawa sand interface. Again, the nonlinear and stick-slip behavior property along the HDPE/Ottawa sand interface is observed.

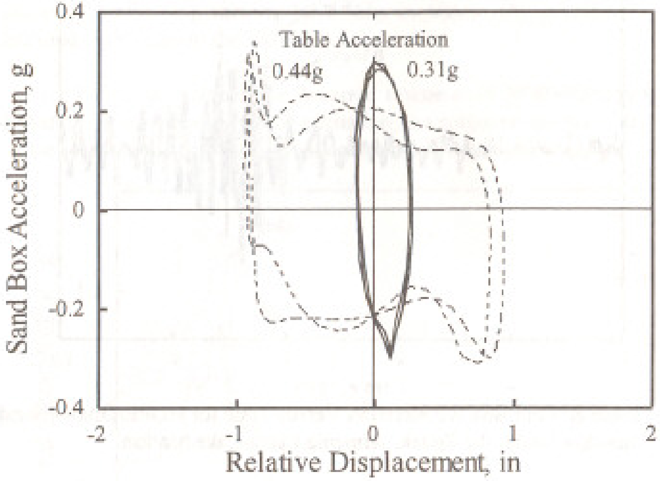

Figure 10. Sand Box Acceleration (Interface Shear Force)-Relative Displacement Relationship for HDPE/Ottawa Sand Interface.

Geomembrane / Ottawa Sand Interface Under Transient Motion

Geomembrane/Ottawa sand interface shear characteristics under typical earthquake excitations was also investigated. Figure 11 shows typical results from tests where the shaking table motion used was the record of the 1988 Spitak, Armenia earthquake scaled to 0.4g.

As the test results indicate, during a typical earthquake motion the dynamic response of the sand box is more complex than that observed under steady state harmonic excitation. A visual comparison of the sand box acceleration response with that of the table shows that the box peak acceleration beyond which the slip occurs varies during the earthquake type of shaking. At the first major pulse of the table, the HDPE/Ottawa sand interface transmitted a maximum acceleration of about 0.22g. Yet, during subsequent pulses, this acceleration was as low as 0.18g and as high as 0.3g. Hence, under earthquake type excitation, the yield acceleration associated with the HDPE/Ottawa sand interface is not constant and is difficult to define. This observation is important to bear in mind when deformation analyses for a landfill is performed using methodologies that typically consider a constant yield acceleration associated with a slip surface. The authors are developing improved techniques for deformation analysis that appropriately will consider the true interface properties along geosynthetics. Figure 12 shows the recorded relative displacement corresponding to the test results shown in Figure 11.

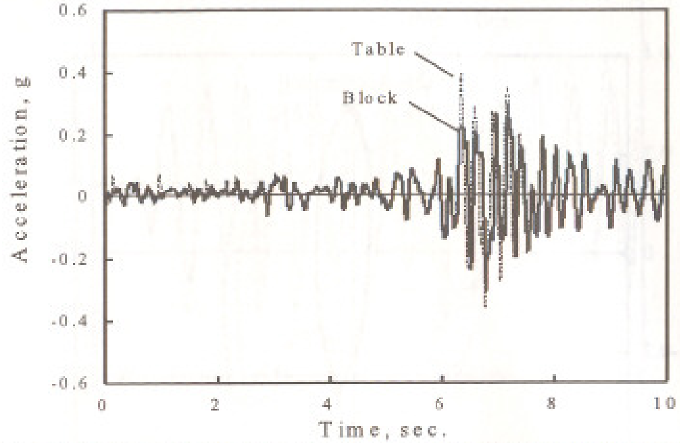

Figure 11. Table & Sand Box Acceleration Versus Time for HDPE/Ottawa Sand Interface Under the Spitak, Armenia Earthquake Motion.

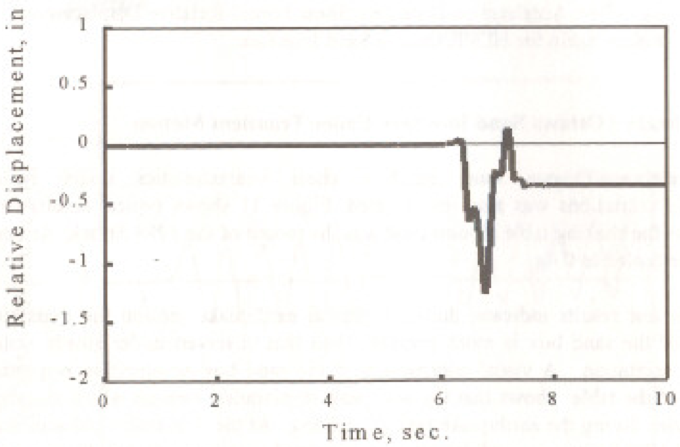

Figure 12. Relative Displacement Versus Time for HDPE/Ottawa Sand Interface Under the Spitak, Armenia Earthquake Motion.

The results show that the Armenia record scaled to a peak acceleration of 0.4g induced along the HDPE/Ottawa sand interface, a maximum slip of about 1.2 inches and a permanent slip of about 0.4 inch. It is noted that these values of slip are for the HDPE/Ottawa sand interface when tested horizontally. Slip deformations can be extremely large if the interface is inclined. The authors are currently performing shaking table tests in which the interface is placed on an inclined table fixed to the shaking table.

To further understand the dynamic response of HDPE/Ottawa sand interface tested under earthquake type of excitation, the response spectra of the shaking table as well as the sand box motion are compared in Figure 13.

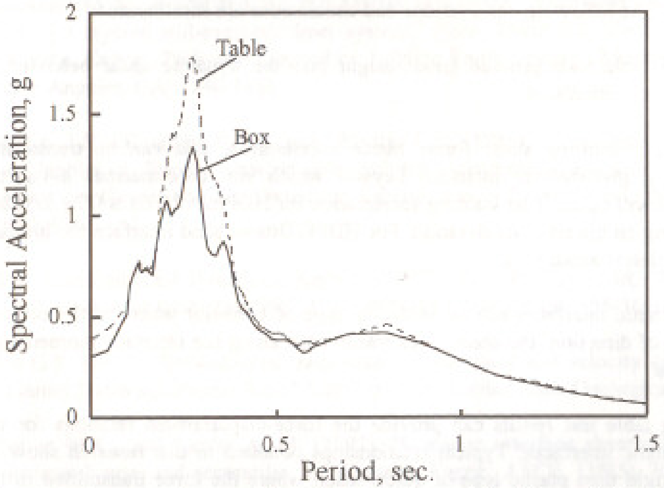

Figure 13. Response Spectra of the Table Motion and that Transmitted Through the HDPE/Ottawa Sand Interface Tested Under the Spitak, Armenia Earthquake Motion Scaled to 0.4g.

This figure demonstrates that when the table peak acceleration was 0.4g (acceleration at period T = 0 sec.) the sand box peak acceleration was as stated earlier 0.3g. It also shows that the frequency content of the motion transmitted through the geomembrane/sand interface is similar to that of the earthquake motion prescribed to the table. Furthermore, because of the HDPE/Ottawa sand interface, the maximum spectral response is reduced from 1.75g to 1.3g ; by about the same ratio as the reduction in the peak acceleration from 0.4g to 0.3g. This is so because, for the record used, the maximum spectral acceleration is primarily dictated by the main pulse carrying the peak acceleration of the record. In general, the reduction in the response spectral values, because of the geosynthetic interface, will depend on the nature of the earthquake time history considered.

Nevertheless, it is clear that the presence of a geosynthetic interface, which has a weaker shear strength properties than that of the surrounding soil or landfill material, has the effect of absorbing wave energy through interface slip. In fact, the geosynthetic interface is acting as base isolation. Such effects and potential benefits of using geosynthetics as base isolation have been described by Kavazanjian et al. (1991) and Yegian and Lahlaf (1992).

Summary and Conclusions

Results of shaking table tests on geosynthetic interfaces were presented and discussed. The following observations and conclusions are summarized:

1-Shaking table tests provide good insight into the dynamic shear behavior of geosynthetic interfaces.

2-There is a limiting shear force, hence acceleration, that can be transmitted through a geosynthetic interface beyond which slip deformations along the interface will occur. This limiting acceleration for HDPE/Polyfelt is 0.2g to 0.24g depending on the table acceleration. For HDPE/Ottawa sand interface the limiting acceleration is about 0.3g.

3-Geosynthetic interfaces exhibit stick-slip type of behavior where at the time of reversal of direction, the shear force transmitted along the interface momentarily increases.

4-Shaking table test results can provide the force-displacement relations for the geosynthetic interfaces. Typical relationships obtained in this research show an almost rigid then plastic type of deformation where the force transmitted in the plastic range increases with increasing slip deformation.

5-Under earthquake excitations, the dynamic shear behavior of geosynthetic interfaces is quite complex. During shaking, the acceleration beyond which slip occurs (yield acceleration), changes from one pulse to another. Hence, in a seismic analysis of a landfill, one should be cautious when using procedures for calculating permanent deformations assuming a constant yield acceleration.

6-The response spectrum of the motion transmitted through geosynthetics can provide valuable information regarding the dynamic shear properties of the interface tested.

Acknowledgment

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Appendix I. References

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